

# *LHC Collimation Studies with Dimad*

*(Tracking with Dimad wherein  
the Struct module was implemented)*

- briefly on system design and optimization

LHC coll. system = IR7 (betatron) and IR3 (momentum)

- primary impact distribution (why 1  $\mu\text{m}$  ?)
- multiturn impact distribution at primary
- losses in collimators
- integrated inefficiency (no apertures)
- 2-cm aperture at all drifts

– ideal system at injection and collision

– eff. of error orbit and coll. misalignments  
(injection only)

THANKS:

*ROGER SERVIRANCKX for DIMAD, IGOR BAICHEV for STRUCT*

RALPH ASSMANN, J.-B. JEANNERET, Thys Risselada,

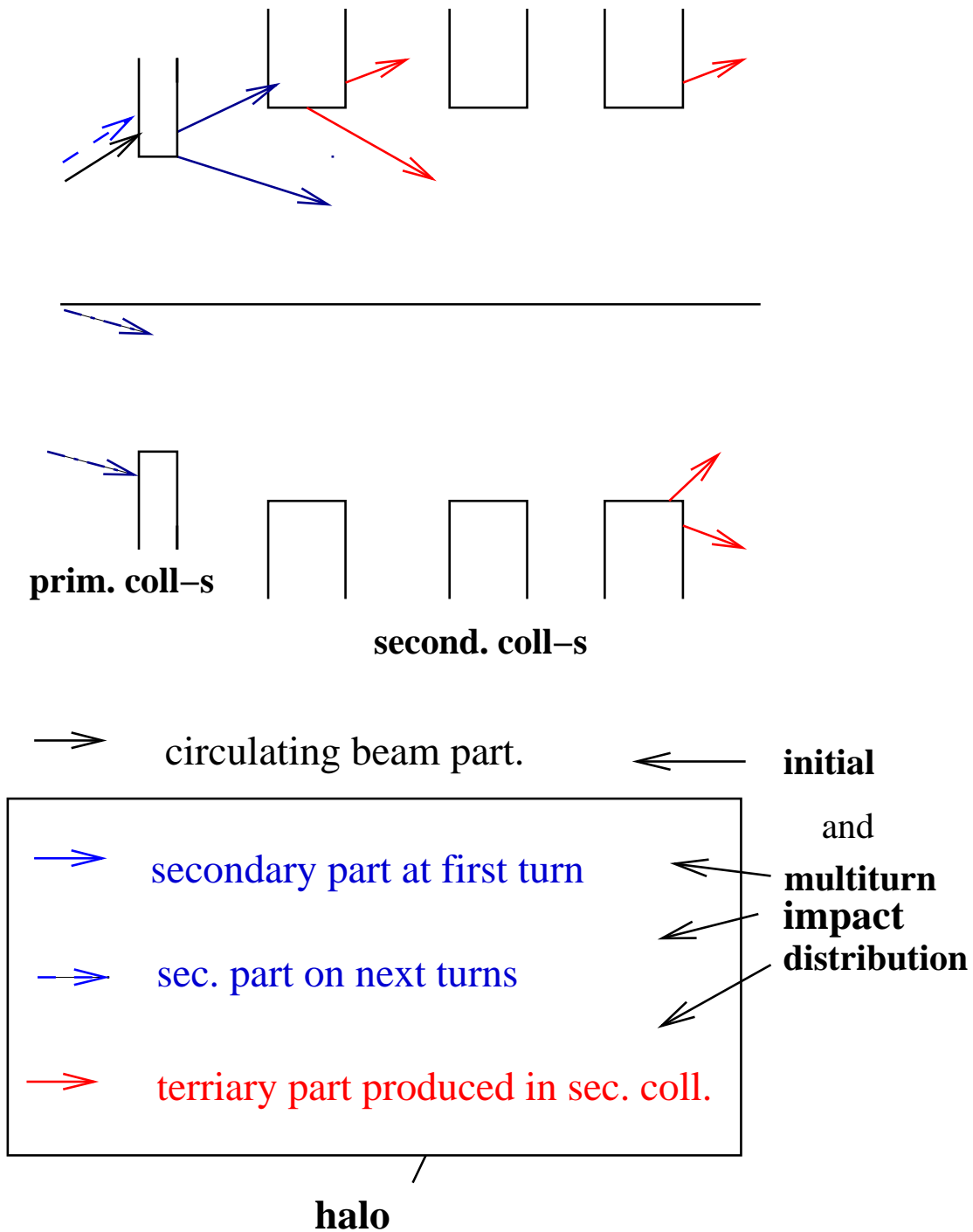
Andre Verdier, Nuria Catalan, Francesco Ruggiero, Oliver

Bruening (CERN), Nikolai Mokhov, Alexandr Drozhdin

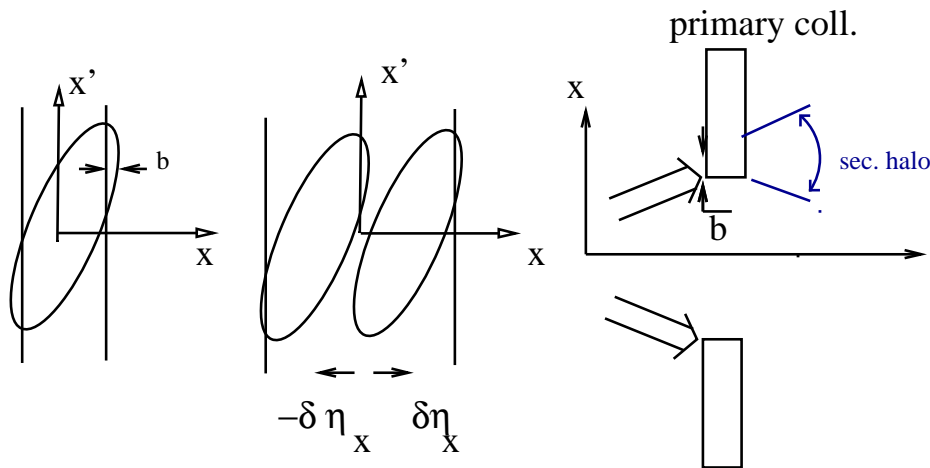
(FNAL), Chris Warsop (RAL), Fred Jones, Shane Koscielniak

(TRIUMF)

*First to define the halo:*



*Initial impact distribution (of the circ. beam on the prim. coll.)*

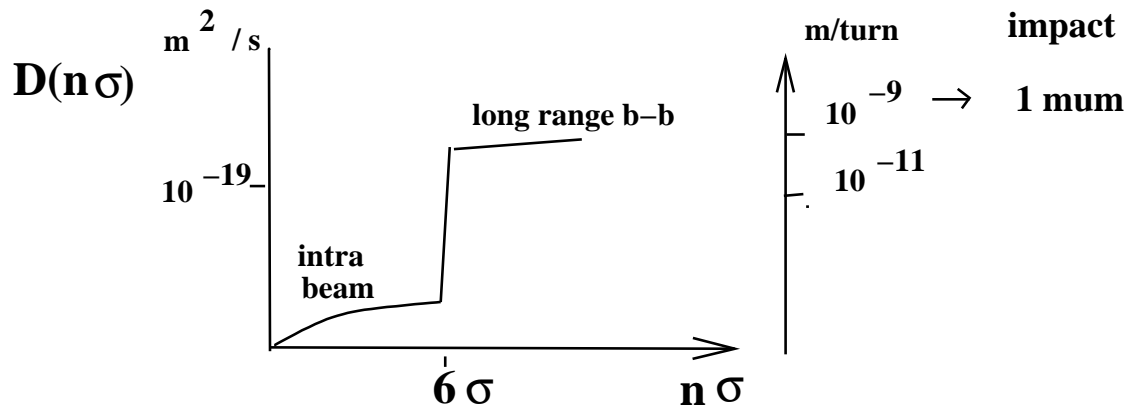


initial distribution of beam impacts  $b \sim 1\mu m$

interplay between

- 1) Sampling of the ellipse with tune Far from resonances ellipse segments are uniformly populated
- 2) The external noise (say from beam-beam). For small diffusion coeff., the overlap segment between ellipse and jaw also cannot be large

*Initial impact distribution (of the circ. beam on the prim. coll.)*



1) change of action variance per turn  $\Rightarrow$   
model diff. coeff  $D \Rightarrow$  losses with time on  
absorb. wall

*ASSMANN, SCHMIDT, ZIMMERMANN, ZORZANO, EPAC 02*

2) measured at Hera and SPS

$$D = 5 \cdot 10^{-19} m^2/sec$$

3) the numerical simulation of the  
equilibrium distr. *DISSERT. OF M. ZEIDEL*

4) role of resonances *T. RISSELADA for ISR*

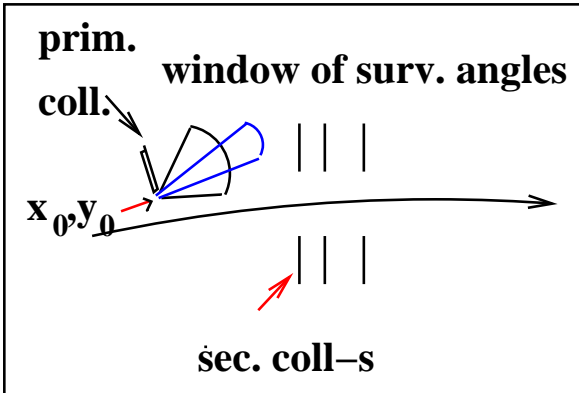
impact = 1 mum or smaller  
with accidents ... much larger

## Maximum invariants surviving single passage through black secondary coll-s

Code DJ = "Distribution of Jaws"

$$A_{x,\max}^{(1)} \quad A_{y,\max}^{(1)} \quad A_{r,\max}^{(1)}$$

$$x'_{\max}, y'_{\max} \quad \text{normalized}$$

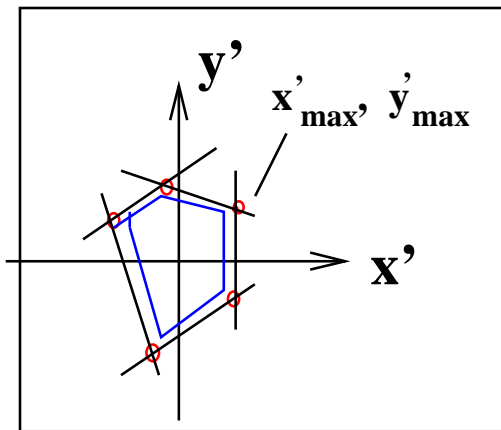


$$A_x = (2J_x / \varepsilon_x)^{1/2} = (x^2 + x'^2)^{1/2}$$

$$A_r = (A_x^2 + A_y^2)^{1/2}$$

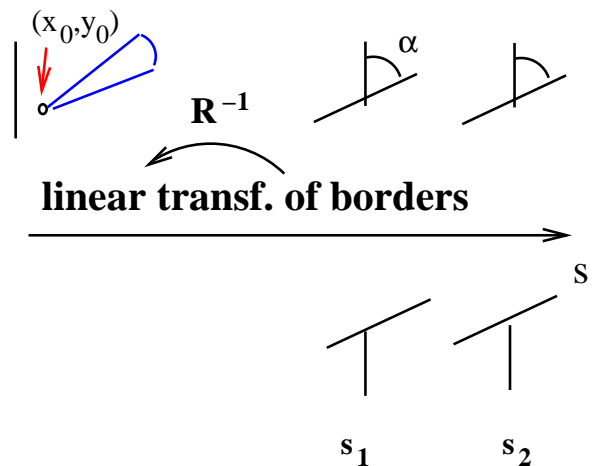
$$A_{x,\max}^{(1)} \quad A_{y,\max}^{(1)} \quad A_{r,\max}^{(1)}$$

all functions of  $x_0, y_0$  and  $dp/p$



initial angle space at primary  
window of surv. angles

## DJ procedure



## Optimization of optics and sec. coll. locations and angles

by minimizing  $A_{x,\max}^{(1)} \quad A_{y,\max}^{(1)} \quad A_{r,\max}^{(1)}$

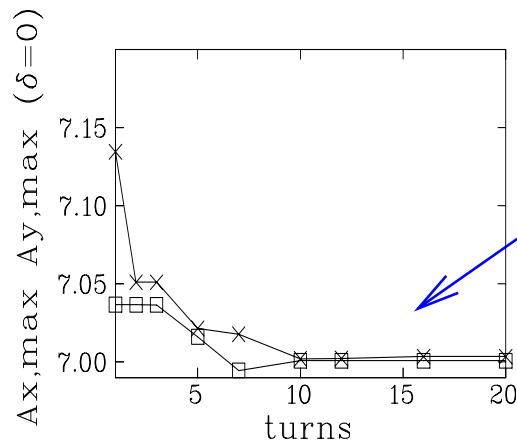
# Maximum surviving amplitudes for N turns

$$A_{x,\max}^{(N)}$$

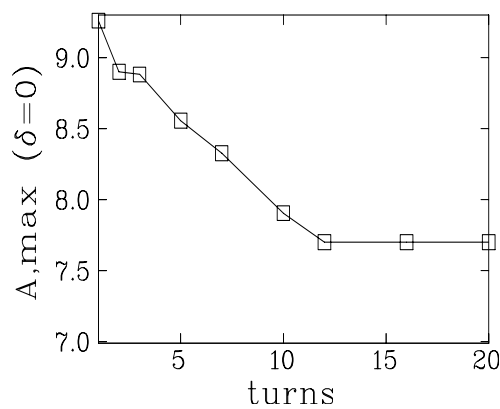
$$A_{y,\max}^{(N)}$$

$$A_{r,\max}^{(N)}$$

code DJ



The window narrows with turns reaching saturation in 10 turns this means part. with  $A > A_r$  will hit a secondary in  $< 10$  turns

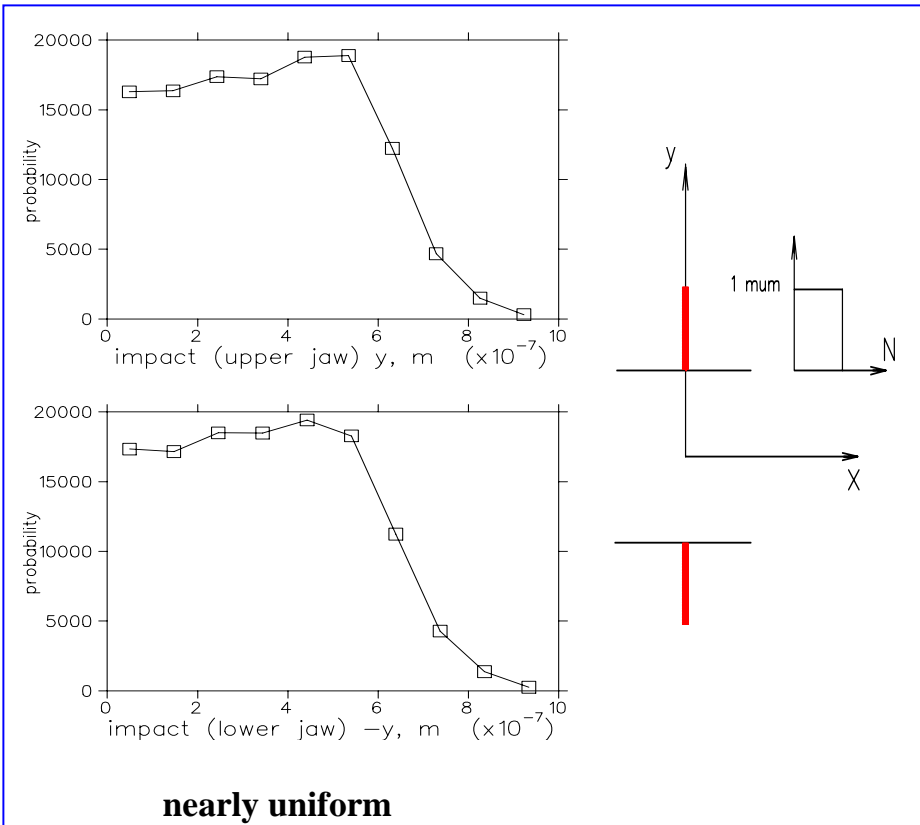


the secondary halo and the multiturn impact distr. on the primary(ies) are restricted from above

Next we see that the mult. imp distr is formed in around 10 turns

## *Dimad tracking*

**Primary impact distr is generated with  
BEAM and GENERATE commands at first  
primary (vertical) of IR7;  $\delta = 0$ ;  
nearly uniform,  $\sim 1 \mu\text{ m}$  wide**





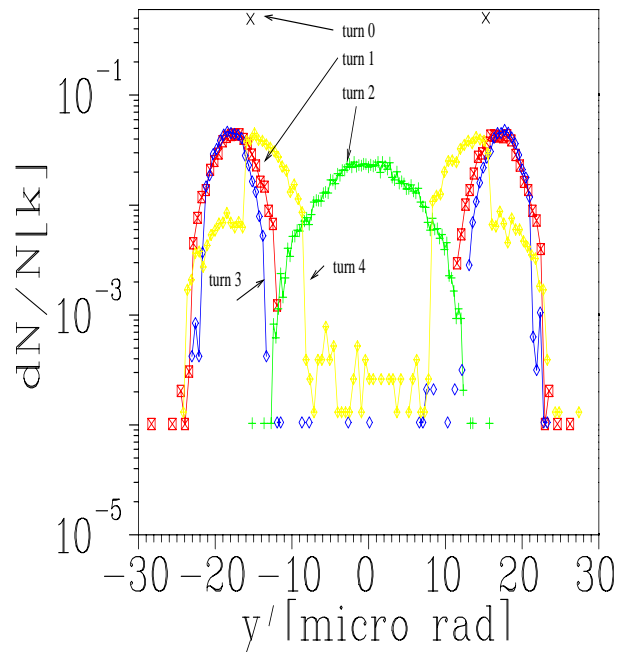


## Dimad tracking at collision energy

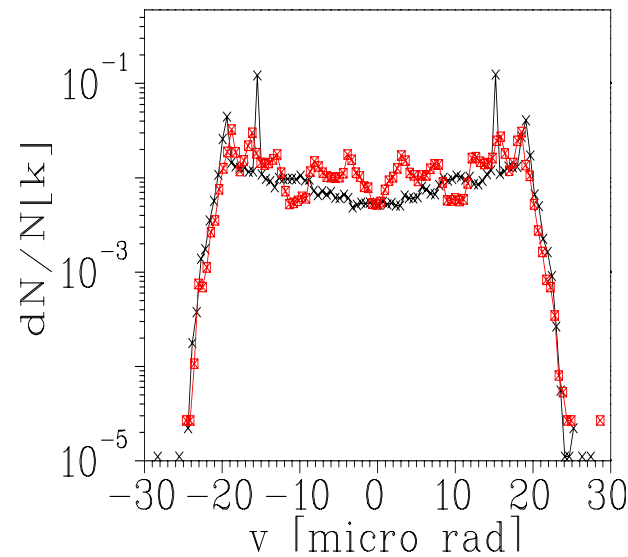
"The multiturn impact distr. is formed in 10 turns  
and then it remains unchanged (only number of part decreases).

Here: example: vertical angle  $y'$

number of part. in  $y', y'+dy'$   
during 10 turn window  
normal. to number survived  
to the entr. of this window



during the first 5 turns



turns 0 to 11

turns 10–20

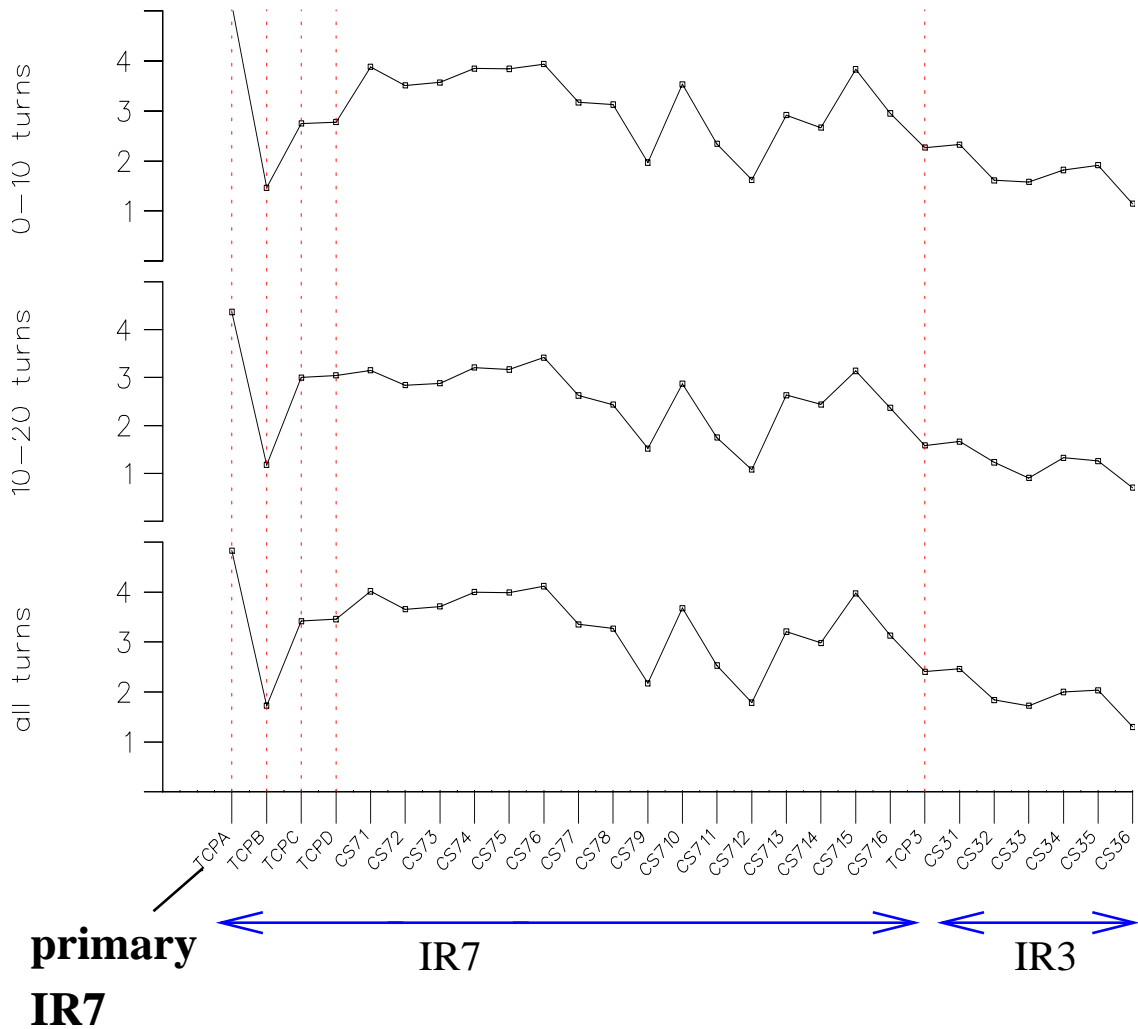
## Dimad tracking at collision

Losses in collimators over turns 0–10, 10–20 and all turns.

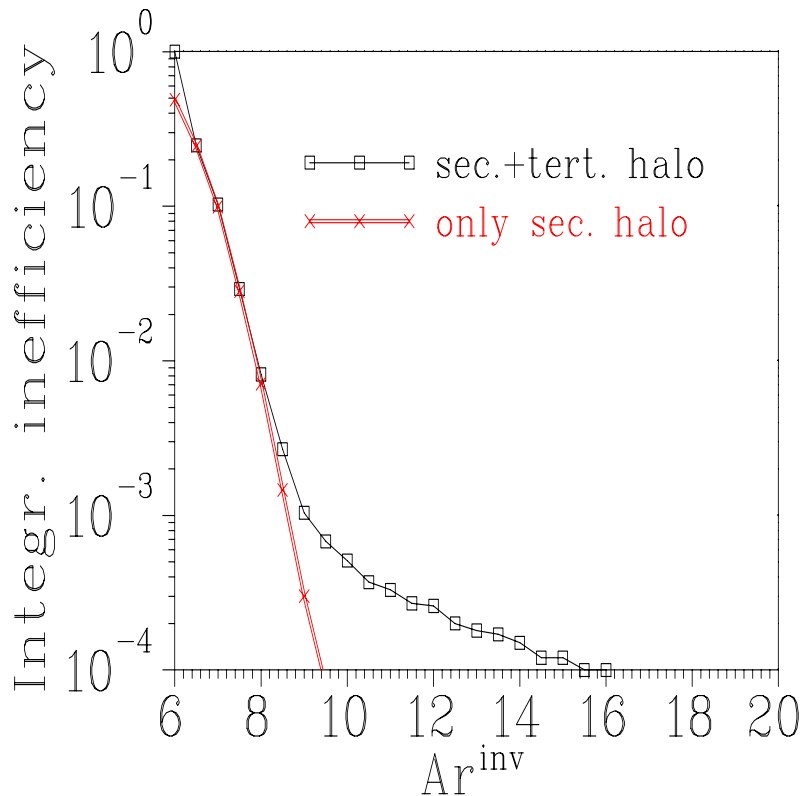
The halo is born at first IR7 prim. (TCPA)

$2.5 \cdot 10^4$  part 150 turns

log(Nlost) Tot part: 0.250E+06 Tot turns:150 Fract lost in coll.=0.99798



*Dimad tracking: Integrated inefficiency. No apert. limits besides collimators.*



- ***Integr. ineff.*** is the fraction lost on an abstract absorber standing at rad. ampl.  $A_r$ .
- Since all the halo is born at  $n_1=6$ ,  $\text{int. ineff} = 1$  for  $A_r = 6$ .
- If only sec halo (red), then  $A_r \sim 9.2$   
This is the design criterion  
(same as the DJ code predicts – well known)
- We better use  $A_r^{\text{inv}}$ . Then the curve is independent on the lattice location chosen.  $\rightarrow$

At location  $s$  store  $x, p_x, y, p_y, \delta \equiv dp/p$

and compute invariant :  $A_r^{inv} \equiv \sqrt{(A_x^{inv})^2 + A_y^2}$

or non – invar. :  $A_r \equiv \sqrt{A_x^2 + A_y^2}$

$$A_x^2 = \left( \frac{x}{\sigma_x} \right)^2 + \left( \frac{\alpha_x x + \beta_x p_x}{\sigma_x} \right)^2$$

$$(A_x^{inv})^2 = 2J_x / \epsilon_x =$$

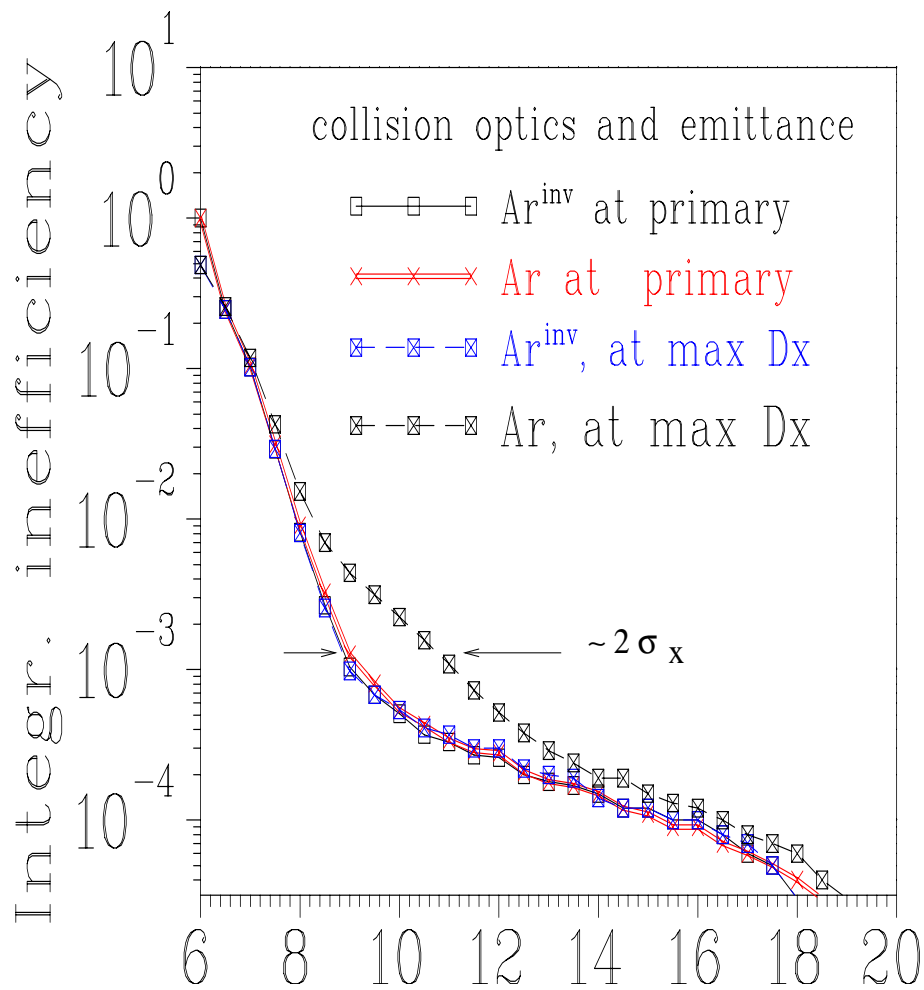
$$= \left( \frac{x - \delta D_x}{\sigma_x} \right)^2 + \left( \frac{\alpha_x x + \beta_x p_x}{\sigma_x} - \frac{\alpha_x D_x + \beta_x D'_x}{\sigma_x} \delta \right)^2$$

$J_{x,y}, A_r^{inv} = \text{invariants}$

$\Rightarrow$  *Integr ineff curve is independent on  $s$*

## Dimad tracking – Integrated inefficiency

compare invariant with non-invariant Ar  
at  $Dx=0$  and at max  $Dx=2m$



$\delta = 0.0001$   
corresp. to  
shift of  $1 \sigma_x$   
at max  $Dx$

*Dimad tracking –  $R=2$  cm aperture at all drifts  
(Ideal system)*

fraction of halo lost				
in colli- mators	on the 2 cm aperture			
	RDS7	IP6	IP1,2,5	arcs
<b><i>Collision:</i></b> $10^6$ part., 300 turns				
0.9986	$6 \cdot 10^{-4}$	0	$5 \cdot 10^{-4}$	0
<b><i>Injection:</i></b> 10 seeds $\times 10^5$ part., 150 turns				
0.9985	$1.3 \cdot 10^{-3}$	$8 \cdot 10^{-5}$	0.	$8 \cdot 10^{-5}$

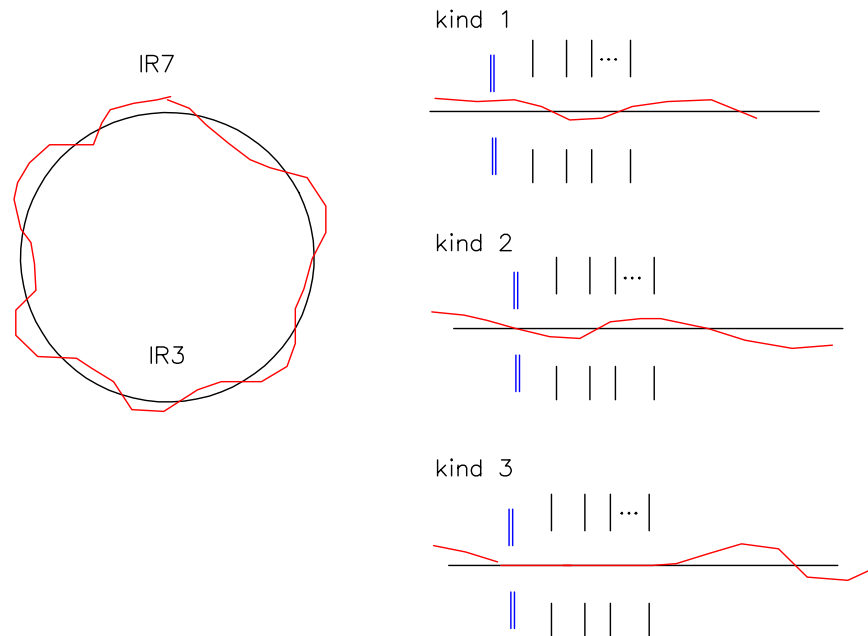
Halo fractions absorbed in collimators and lost on the 2-cm radial aperture (drift entrances) in different ring sections.

The injection values are ***averages of 10 seeds.***

Ring sections:

- collimator occupied reg. of IR7 and IR3,
- Right Dispersion Suppressor in IR7 (RDS7)
- the IP6,
- the high-beta IP-s
- all arcs (= ring 7-3 + ring 3-7 on plots)

## *Possible orbit errors*

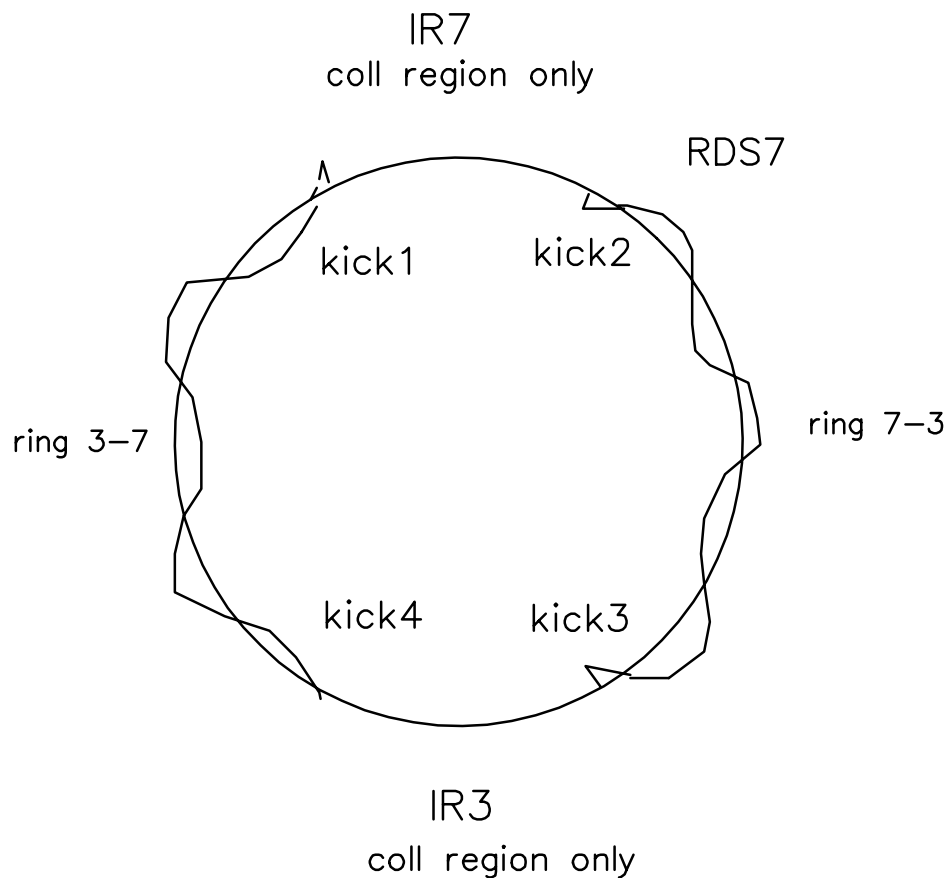


One would like to consider all these and put some jaw misalignment and optics errors on top.

In what follows **we only take kind 3 plus transverse collimator misalignment.**

*Individual misalignment effects considered so far (injection):*

1) sample error closed orbit –  
4 mm peak-to-peak in the arc (by transv. shift of two arc quads) corrected to zero within the two collimator occupied sections with four (coord+angle) kicks:



2) random transverse displacement of the midpoint (center) of each pair of secondary jaws w.r.t. to the vacuum chamber axis;



*indiv. error 3) all momentum collimators (IR3)  
are retracted:*

**For Ideal system the IR3 collimators receive much smaller losses than the betatron (both injection and collision).**

**However at injection introducing IR3 into misaligned system has an improving effect on the worst seeds of the ten (by around 60%).**

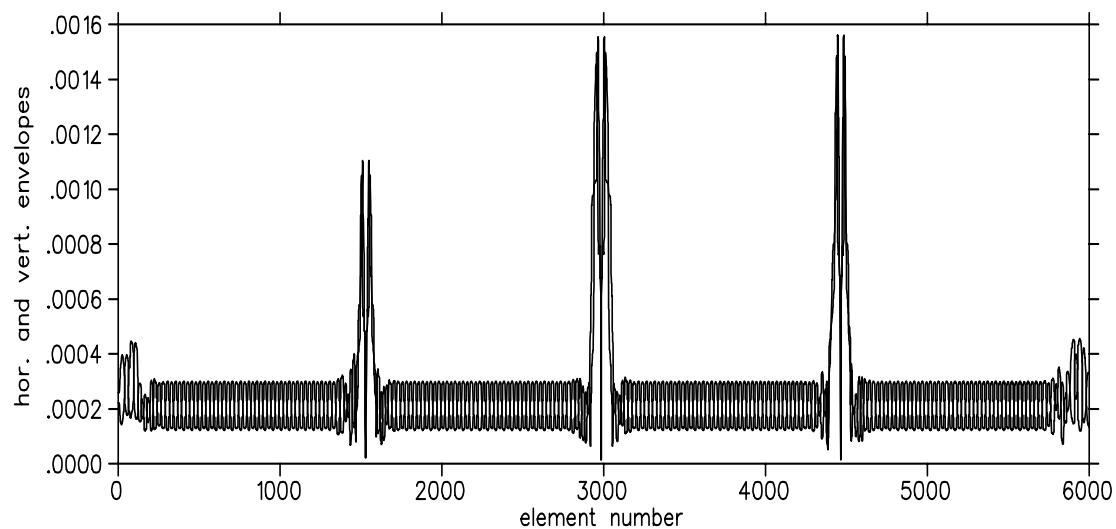
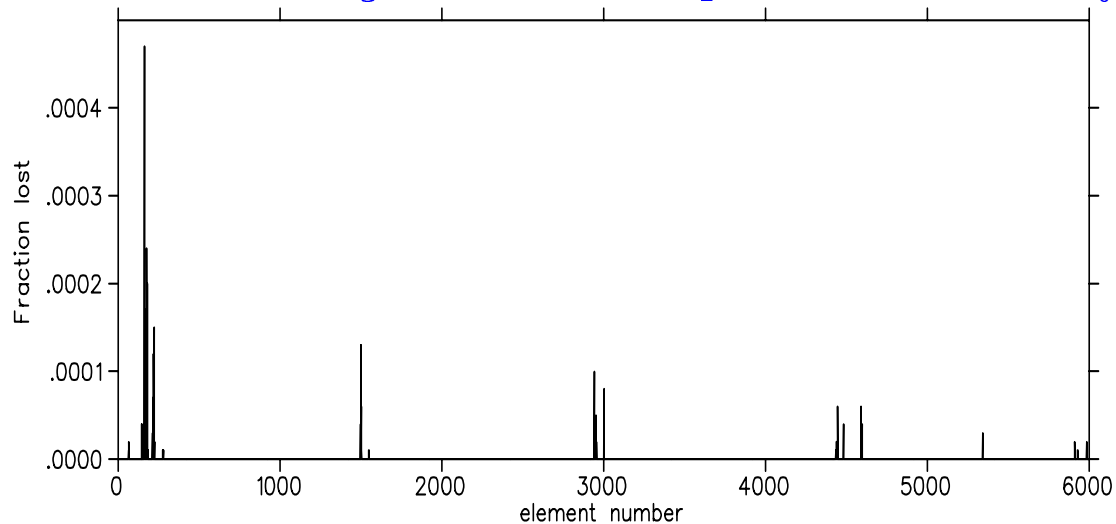
*Dimad tracking –*

*Combined CO error + jaw misalignment (injection)*

fraction lost		
	on the 2 cm aperture RDS7 ( $\times 10^{-3}$ )	arcs + IP6 ( $\times 10^{-4}$ )
Ideal	1.3	1.4
corrected CO	1.5	1.7
corr. CO + 0.5 mm jaw mis.	2	7.4
corr. CO + 1 mm jaw mis.	4.4	18

The seed producing maximum CO effect on Ideal system losses, *combined with the worst seed* transverse misalignment of collimators (last two rows).

## *Dimad tracking – $R=2$ cm aperture at all drifts*



- The top plot shows losses at drift entrances.
- the 2-cm apert. allows to find losses over large ring sections (not the per-meter losses!)  
The allowed per meter is  $\sim 2 \times 10^{-5}$ .